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Review Article

Point-of-care ultrasound of the upper airway in difficult airway management: a systematic review and meta-analysis*

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Summary

Introduction The utility of bedside screening tests for the prediction of difficult airways is limited. There is growing interest in the role of point-of-care-ultrasound in airway assessment and management. This systematic review and meta-analysis aimed to determine the diagnostic utility and clinical application of various upper airway point-of-care-ultrasound parameters in the prediction of difficult airways.

Methods We searched databases for randomised controlled trials, observational studies and case series with more than five cases.

Results In total, 60 studies involving 10,580 patients, evaluating 58 parameters were included. For difficult facemask ventilation, a narrative synthesis showed that increased tongue thickness was associated with an increased incidence of a difficult airway. For prediction of difficult laryngoscopy, the sensitivity, specificity and area under the receiver operator characteristic curve (AUROC) for distance from-skin-to-vocal-cords were 0.84 (95%CI 0.74–0.91), 0.81 (95%CI 0.61–0.92) and 0.87 (95%CI 0.78–0.89), respectively (high certainty of evidence). For prediction of difficult tracheal intubation, distance from skin-to-epiglottis had the highest sensitivity (0.80 (95%CI 0.74–0.85)) and specificity (0.86 (95%CI 0.74–0.91)) (high certainty of evidence), while distance from skin-to-hyoid had the highest AUROC of 0.86 (95% CI 0.73–0.92), with a sensitivity and specificity of 0.78 (95%CI 0.60–0.89) and 0.81 (95%CI 0.63–0.91), respectively (moderate certainty of evidence). Ultrasound use was associated with higher first pass success in percutaneous tracheostomy (odds ratio (95%CI) 3.9 (2.1–71), (low-moderate certainty of evidence)) and improved cricothyroid membrane identification compared with palpation (odds ratio (95%CI) 3.61 (2.20–5.92) (moderate-high certainty of evidence)).

Discussion Upper airway point-of-care ultrasound may improve prediction of difficult airways; its use is associated with improved first pass success in percutaneous tracheostomy. Future research should focus on evaluating its use in combination with a focused history and standard bedside examination tests, and in at-risk patient populations.

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Plain Language Summary may be found on PubMed and in the Supporting Information.

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Introduction

Reliable and timely identification of difficult airways is important for planning and implementation of safe airway management. Bedside clinical airway evaluations are poor predictors of difficult airways [1, 2] but these tests remain the mainstay for airway assessment and are recommended by airway management guidelines and algorithms [3, 4].

The use of point-of-care ultrasound (POCUS) is growing and there is interest in its role as an adjunct in airway assessment and management [5–7]. It provides detailed anatomical information about the upper airway [5]. Contemporary applications of POCUS include detecting upper airway pathology; determining the appropriate size and type of airway device needed; confirming tracheal intubation; facilitating cricothyrotomy/tracheostomy; and assessing post-extubation stridor [5–7]. Previous research has shown that some POCUS parameters, such as tongue thickness, distance from skin-to-epiglottis and distance from skin-to-vocal cords, perform better than traditional clinical evaluation tools for prediction of difficult facemask ventilation; supraglottic airway device (SAD) insertion; laryngoscopy; tracheal intubation; cricothyrotomy; and tracheostomy [8–10]. However, a comprehensive evaluation of the use of POCUS airway assessment and its application to current airway management guidelines is lacking [3, 4].

This systematic review and meta-analysis aimed to determine the diagnostic utility and clinical application of various upper airway POCUS parameters for the prediction of difficult airways [3, 4].

Methods

This systematic review and meta-analysis was conducted and reported in accordance with PRISMA recommendations [11], using standard methods. A systematic search was conducted from inception to 26 March 2024. The following databases were searched: MEDLINE; Embase; Cochrane Central Register of Controlled Trials; Cochrane Database of Systematic Reviews; Web of Science Core Collection; and Scopus. We also searched relevant trial registries.

Randomised controlled trials, prospective cohort studies, cross-sectional studies, case control studies and case series that included adults (aged ≥ 18 y) undergoing pre-operative airway assessment with POCUS to evaluate airway management were included. Our outcomes of interest were the incidence of difficult facemask ventilation; difficult SAD placement; difficult laryngoscopy; difficult tracheal intubation; confirmation of tracheal tube placement; and surgical airway management including tracheostomy and cricothyrotomy tube placement. We did not include case series; review articles; opinion pieces; retrospective studies; studies including children; and studies performing POCUS of the head, neck and thorax that did not relate to upper airway imaging.

Two independent reviewers screened the retrieved studies (titles and abstracts, followed by full text screening). Two independent reviewers screened each study, and a third reviewer (MS) was consulted to resolve any conflicts. Data extraction was completed in duplicate. Studies were grouped according to the POCUS parameter analysed and the airway management procedure being assessed.

Data extraction items included study characteristics (country, study design and funding source); patient characteristics (age, sex, BMI and presence of obstructive sleep apnoea); POCUS operator/setting; definition of difficult airway; study sample size; and proportion of patients with difficult facemask ventilation, SAD insertion, laryngoscopy, tracheal intubation and/or surgical airway placement including cricothyrotomy and/or tracheostomy. In addition, data on clinical outcomes (failed tracheal extubation, tracheal reintubation and ICU admission); method of laryngoscopy (direct vs. video); type of laryngoscopy blade used; type of SAD used; ease of facemask ventilation; ease of tracheal intubation; successful surgical airway placement measures (time to first pass and first pass success rate); and type of surgical airway were collected. Diagnostic accuracy parameters including: values for sensitivity; specificity; positive predictive value; negative predictive value; area under the receiver operator characteristic curve (AUROC); and likelihood ratios were also collected.

Risk of bias was assessed depending on the study type. Diagnostic accuracy studies were evaluated using the Quality of Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool, randomised controlled trials were evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool and non-randomised intervention studies were evaluated using the Risk of Bias in Non-randomised Studies – of Interventions (ROBINS-I) tool. Risk of bias was visualised using the Robvis tool [12–15].

Studies were divided into six sections depending on the airway management procedure being assessed: facemask ventilation; SAD insertion; laryngoscopy; tracheal intubation; cricothyrotomy; and tracheostomy. Wherever applicable, data related to each parameter were pooled in a random effects model using RevMan software, version 5.4.1 (Cochrane collaboration) [16]. Data were only pooled if three or more studies provided data for that specific parameter; otherwise, a narrative synthesis was conducted. R version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria) was used to synthesise diagnostic accuracy

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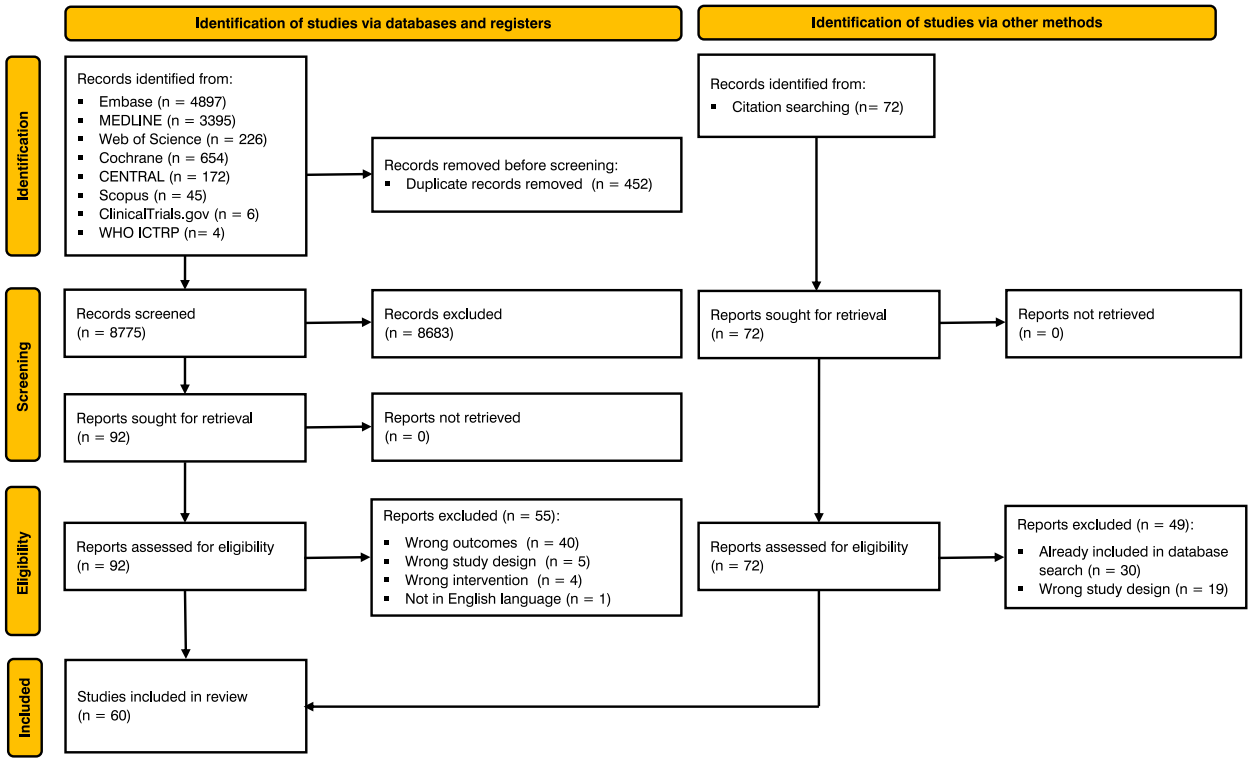
Identification of studies via databases and registers
Identification of studies via other methods
Identification
Records identified from:
Embase (n = 4897)
MEDLINE (n = 3395)
Web of Science (n = 226)
Cochrane (n = 654)
CENTRAL (n = 172)
Scopus (n = 45)
ClinicalTrials.gov (n = 6)
WHO ICTRP (n= 4)
Records removed before screening:
Duplicate records removed (n = 452)
Records identified from:
Citation searching (n= 72)
Screening
Records screened (n = 8775)
Records excluded (n = 8683)
Reports sought for retrieval (n = 72)
Reports not retrieved (n = 0)
Reports sought for retrieval (n = 92)
Reports not retrieved (n = 0)
Eligibility
Reports assessed for eligibility (n = 92)
Reports excluded (n = 55):
Wrong outcomes (n = 40)
Wrong study design (n = 5)
Wrong intervention (n = 4)
Not in English language (n = 1)
Reports assessed for eligibility (n = 72)
Reports excluded (n = 49):
Already included in database search (n = 30)
Wrong study design (n = 19)
Included
Studies included in review (n = 60)

Figure 1 Study flow diagram. WHO ICTRP, World Health Organization International Clinical Trials Registry Platform.

measurements, produce funnel plots and produce summary AUROC curves.

Heterogeneity between studies was assessed qualitatively (patient population, risk of bias, and reported outcome measures) and quantitatively using the I^2 statistic [17]. Sensitivity analysis was conducted by excluding high risk of bias studies, and estimates were compared where applicable. Estimated mean effects for each study were calculated with respective standard errors and pooled effects were then assessed. A p value of < 0.05 was considered statistically significant. Publication bias was assessed using visual inspection of funnel plots for our outcomes of interest. We used GRADE methodology to assess the quality of the evidence of using POCUS for both diagnostic accuracy testing and guiding intervention [18].

Results

The search identified 13,847 articles. After screening and full text review, 60 studies involving 10,580 participants were included in this systematic review (Fig. 1). Our search returned no studies that focused on SADs. Some studies analysed POCUS across multiple procedures; therefore, there is some overlap in the number of patients. Summary characteristics of the included studies are displayed in Table 1, with detailed information on each study in online Supporting Information Tables S1 and S2.

All studies evaluating laryngoscopy used the Cormack and Lehane score [19] as the gold-standard for identifying a difficult airway. Definitions for difficulty airway and tracheal intubation varied between studies. Srinivasarangan et al. used a Cormack and Lehane score of 2b, 3 or 4 [20], while Agarwal et al. defined difficult tracheal intubation as ``*placement of the endotracheal tube by using conventional laryngoscopy that required > 2 attempts, lasted > 10 min or required alternate methods*'' [21]. Some studies used the tracheal intubation difficulty scale or created their own scales based on certain procedures required during surgery [20–24]. Studies evaluating facemask ventilation were evenly split between the Hans Scale [25] and criteria created by the authors themselves (often a 4- or 5-point scale) [24, 26]. Only three studies evaluating cricothyrotomy outlined their definition of a difficult airway, and each study used a different definition [27–29]. No studies evaluating tracheostomy insertion provided a definition of a difficult airway.

Obstructive sleep apnoea status was reported in four studies, of which three evaluated laryngoscopy and one assessed facemask ventilation [30–32]. Mean BMI ranged

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Table 1 Summary characteristics of included studies. Values are number.

Outcome	Number of included studies	Patients	Clinical settings
Facemask ventilation			
- Tongue thickness	3 (Observational = 3)	592	Pre- and postoperative
- Distance between lingual arteries	3 (Observational = 3)	168	Pre- and postoperative
Laryngoscopy			
- Distance from skin to epiglottis	14 (Observational = 12; cross-sectional = 2)	2820	Pre-, intra- and postoperative
- Distance from skin to hyoid bone	9 (Observational = 7; cross-sectional = 2)	1258	Pre- and intra-operative
- Distance from skin to vocal cords	4 (Observational = 3; cross-sectional = 1)	854	Pre- and intra-operative
- Tongue volume	4 (Observational = 3; cross-sectional = 1)	609	Pre-, intra- and postoperative
- Tongue thickness	3 (Observational = 3)	2498	Pre- and postoperative
Tracheal intubation			
- Distance from skin to epiglottis	8 (Observational = 7; cross-sectional = 1)	2112	Pre- and intra-operative
- Distance from skin to hyoid bone	3 (Observational = 5)	1493	Pre-operative
- Distance from skin to vocal cords	3 (Observational = 3)	300	Pre-operative
- Hyomental distance ratio of 1	3 (Observational = 3)	345	Pre-operative
- Pre-E/E-VC ratio	4 (Observational = 3; cross-sectional = 1)	469	Pre-operative
Cricothyrotomy			
- Accuracy of cricothyroid membrane detection	3 (Observational = 2; RCT = 1)	156	Pre-operative and a teaching setting with healthy volunteers
Tracheostomy			
- First pass success rate	4 (RCT = 3; NRS = 1)	474	Bedside, pre- and postoperative

NRS, non-randomised study; Pre-E/E-VC, ratio between pre-epiglottic distance and epiglottis-to-vocal-cords distance; RCT, randomised controlled trial.

from 23.3 to 60.1 $kg.m^{-2}$, and 11 studies specifically focused on patients undergoing bariatric surgery [30, 32–41]. Differences between patient sex in predicting difficult airways were observed in 21 studies but with conflicting results. Three studies determined that sex was not associated with difficult airway prediction using POCUS [42–44]. Five studies found that male patients were more likely to have a difficult airway [26, 37, 45–47]. Ni et al. found that the best performing prediction model included male sex [47], though a multivariate analysis by Komatsu et al. did not identify sex as an independent predictor of difficult laryngoscopy [33].

Of the 43 studies analysed for risk of bias using the QUADAS-2 tool for diagnostic accuracy studies, four studies were at high risk of bias in the patient selection domain, as they either used a case–control study design or avoided random/convenience sampling [21, 27, 39, 48]. Two studies were at high risk of bias in the flow and timing domain for patient exclusion in their data analysis [24, 33]. Zheng et al. was at high risk of bias in every domain [22], and Mohammadi et al. had a high risk of bias in every domain except for patient selection [49]. The Cochrane RoB 2 tool was used to analyse six randomised controlled trials evaluating the use of POCUS in tracheostomy and cricothyrotomy procedures. In randomised controlled trials evaluating tracheostomy, Kupeli et al. was at high risk of bias in the allocation concealment domain [50]. The ROBINS-I tool was used to assess nine observational studies investigating percutaneous dilatational tracheostomy. Three studies were at high risk of bias due to confounding [51–53]. Reasons included inadequate stratification of results based on the experience of the clinicians performing the procedure [51]; no consideration of the cost of tracheostomy within their own healthcare region when performing a cost–benefit analysis [49]; and explicitly stating the uncontrolled nature of the study [53]. Results are displayed in online Supporting Information Figure S1. Publication bias for distance from skin-to-epiglottis and skin-to-hyoid bone parameters in laryngoscopy was high, while tongue volume, thickness and distance from skin-to-vocal cords was low (online Supporting Information Figure S2). Publication bias in tracheal intubation was low with the exception of studies investigating the distance-from-skin-to-hyoid-bone (online Supporting Information Figure S3). Publication bias in surgical airway studies was also low (online Supporting Information Figure S4).

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Table 2 Performance of POCUS parameters for prediction and management of difficult airways.

Outcome	Mean cut-off (95%CI)	Sensitivity (95%CI)	Specificity (95%CI)	AUROC (95%CI)	I^2	Certainty of evidence
Laryngoscopy						
- Distance from skin to vocal cords; cm	6.0 (4.7–7.3)	0.84 (0.74–0.91)	0.81 (0.61–0.92)	0.87 (0.78–0.89)	1.8%	High
- Distance from skin to epiglottis; cm	2.7 (1.9–3.5)	0.73 (0.64–0.81)	0.78 (0.69–0.86)	0.81 (0.69–0.87)	0%	Moderate
- Distance from skin to hyoid bone; cm	-	0.69 (0.52–0.83)	0.70 (0.50–0.84)	0.75 (0.59–0.90)	24.0%	Moderate
- Tongue volume; cm^3	101 (83–120)	0.57 (0.20–0.88)	0.78 (0.37–0.96)	0.73 (0.66–0.78)	0%	Moderate
Tracheal intubation						
- Distance from skin to hyoid bone; cm	-	0.78 (0.60–0.89)	0.81 (0.63–0.91)	0.86 (0.73–0.92)	18.0%	Moderate
- Distance from skin to epiglottis; cm	2.4 (1.7–3.0)	0.80 (0.74–0.85)	0.86 (0.74–0.91)	0.82 (0.78–0.91)	6.2%	High
- Hyomental distance ratio	-	0.69 (0.52–0.81)	0.80 (0.73–0.86)	0.80 (0.72–0.87)	0%	High
- Distance from skin to vocal cords; cm	-	0.80 (0.63–0.91)	0.62 (0.55–0.70)	0.71 (0.62–0.82)	0%	Moderate
- Pre-E/E-VC ratio	1.9 (1.5–2.2)	0.56 (0.06–0.97)	0.70 (0.31–0.92)	0.69 (0.30–0.86)	15.0%	Moderate
	Odds ratio (95%CI)					
Cricothyrotomy						
- Cricothyroid membrane detection	3.61 (2.20–5.92)	n/a	n/a	n/a	0%	Moderate
Tracheostomy						
- First pass success rate	3.89 (1.87–6.51)	n/a	n/a	n/a	0%	Moderate

Pre-E/E-VC, ratio between pre-epiglottic distance and the epiglottis and vocal cords distance.

Summary results for the performance of different POCUS parameters in the prediction and management of difficult airways are displayed in Table 2. The overall certainty of the evidence ranged from high to very low, and common reasons for downgrading included concerns regarding risk of bias; serious imprecision; and publication bias (online Supporting Information Tables S3 and S4). Heterogeneity varied depending on the parameter and outcome being evaluated. Pooled diagnostic data showed low heterogeneity with I^2 ranging from 0% to 15.3% across all studies evaluating laryngoscopy and tracheal intubation. Conversely, pooling of mean values resulted in I^2 ranging between 75.0% and 98.0%. Studies evaluating surgical airways had low heterogeneity with I^2 of 0%.

Facemask ventilation

All included studies indicated that tongue thickness was predictive for difficult facemask ventilation [26, 27, 34, 54]. Two studies found that the distance between lingual arteries may also be a predictor for difficult facemask ventilation [27, 34].

Laryngoscopy

Distance from skin to vocal cords

Of the studies that investigated distance from skin to vocal cords, four provided diagnostic data [37, 55–57]. Pooled sensitivity, specificity and AUROC for this parameter were the highest of all investigated parameters, with values of 0.84 (95%CI 0.74–0.91), 0.81 (95%CI 0.61–0.92) and 0.87 (95%CI 0.78–0.89) respectively (Table 2, online Supporting Information Figure S5). The certainty of evidence was judged to be high (online Supporting Information Table S3).

Distance from skin to epiglottis

Fourteen studies examined the distance from skin to epiglottis using POCUS [31, 36, 42, 43, 45–47, 56, 58–63] (Table 1). Diagnostic data for the distance from skin to epiglottis were reported in eight studies [47, 56, 58–63]. Pooled sensitivity, specificity and AUROC values were 0.73 (95%CI 0.64–0.81), 0.78 (95%CI 0.69–0.86) and 0.81 (95%CI 0.69–0.87), respectively (Table 2, online Supporting Information Figure S6). The certainty of evidence was moderate, downgraded due to suspected publication bias

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(online Supporting Information Table S3). Eight studies reported the mean distance from skin to epiglottis in both easy and difficult laryngoscopy groups [31, 36, 42, 43, 45–47, 61]. A pooled mean difference of 0.52 cm (95%CI 0.26–0.77) indicated that an increasing distance from skin to epiglottis predicted increasingly difficult laryngoscopy (online Supporting Information Figure S7). The pooled optimal cut-off point was 2.7 cm (95%CI 1.9–3.5) based on data from three studies [45, 46, 59].

Distance from skin to hyoid bone

Of nine included studies [31, 37, 42, 45, 46, 55, 56, 58, 60], eight reported the mean distance from skin to hyoid-bone in patients with difficult and easy laryngoscopy [31, 37, 42, 45, 46, 55, 58, 60]. An increasing distance from skin to hyoid bone was associated with a difficult airway (online Supporting Information Figure S7). Only one study provided a cut-off point of 1.47 cm [37]. Pooled sensitivity, specificity and AUROC values are shown in Table 2 and online Supporting Information Figure S8. The certainty of evidence was judged to be moderate (online Supporting Information Table S3).

Tongue thickness

All three studies reporting data for tongue thickness were included in the analysis [24, 27, 64]. A pooled mean difference of 0.57 cm (95%CI 0.49–0.65) was associated with difficult laryngoscopy when compared with easy laryngoscopy (online Supporting Information Figure S7). Cut-off points were similar and ranged between 5.9 cm [64] and 6.1 cm [24]. The certainty of evidence was judged to be very low (online Supporting Information Table S4).

Tongue volume

Tongue volume, defined by the multiplication of the midsagittal cross-sectional area of the tongue by the tongue width, was evaluated in four studies [22, 60, 65, 66]. Pooled sensitivity, specificity and AUROC values were 0.57 (95%CI 0.20–0.88), 0.78 (95% CI 0.37–0.96) and 0.73 (95%CI 0.66–0.78), respectively (Table 2, online Supporting Information Figure S9). The certainty of evidence was judged to be moderate (online Supporting Information Table S3).

Tracheal intubation

Ratio between pre-epiglottis space and distance between epiglottis and vocal cords (pre-E/E-VC)

Four studies analysed this parameter [5, 44, 67, 68]; an increase in this ratio was associated with difficult tracheal intubation (Table 2, online Supporting Information Figure S10). Pooled sensitivity, specificity and AUROC of this parameter was low with values of 0.56 (95% CI 0.06–0.97), 0.70 (95%CI 0.31–0.92) and 0.69 (95% CI 0.30–0.86), respectively (online Supporting Information Figure S11). Cuff-off ratios ranged from 1.77 to 2.00 [5, 67, 68] and these also correlated with difficult laryngoscopy. The certainty of evidence was judged to be moderate (online Supporting Information Table S4).

Distance from skin to epiglottis

Eight studies provided data on this parameter [20, 21, 43, 46, 62, 63, 69, 70]. Pooled sensitivity, specificity, and AUROC were 0.80 (95%CI 0.74–0.85), 0.86 (95%CI 0.74–0.91) and 0.82 (95%CI 0.78–0.91), respectively (Table 2, online Supporting Information Figure S12). Pooled prevalence of difficult laryngoscopy was 0.15 (95%CI 0.08–0.26), meaning that out of 100 patients, fifteen would have true difficult laryngoscopy. The pooled cut-off point was 2.4 cm (95%CI 2.1–2.8) [20, 21, 46, 63, 69]. The certainty of evidence was judged to be high (online Supporting Information Table S3).

Distance from skin to hyoid bone

Five studies were analysed for this parameter [5, 20, 21, 46, 70], with the pooled sensitivity, specificity and AUROC values 0.78 (95%CI 0.60–0.89), 0.81 (95%CI 0.63–0.91) and 0.86 (95%CI 0.73–0.92), respectively (Table 2, online Supporting Information Figure S13). Cut-offs for this parameter ranged from 0.58 cm [20] to 1.4 cm [21]. The certainty of evidence was moderate (online Supporting Information Table S3).

Hyomental distance ratio 1

The hyomental distance ratio 1 is the ratio of the hyomental distance in the extended position to that in the neutral position. Within the three studies analysed [5, 36, 68], pooled sensitivity, specificity, and AUROC values were 0.69 (95%CI 0.52–0.81), 0.80 (95%CI 0.73–0.86), and 0.80 (95%CI 0.72–0.87), respectively (Table 2, online Supporting Information Figure S14). The certainty of evidence was judged to be high (online Supporting Information Table S3).

Distance from skin to vocal cords

Three studies looked at the distance from skin-to-vocal-cord parameter for difficult tracheal intubation [20, 67, 70]. Pooled sensitivity, specificity and AUROC values were 0.80 (95% CI 0.63–0.91), 0.62 (95% CI 0.55–0.70) and 0.71 (95% CI 0.62–0.82), respectively (Table 2, online supporting

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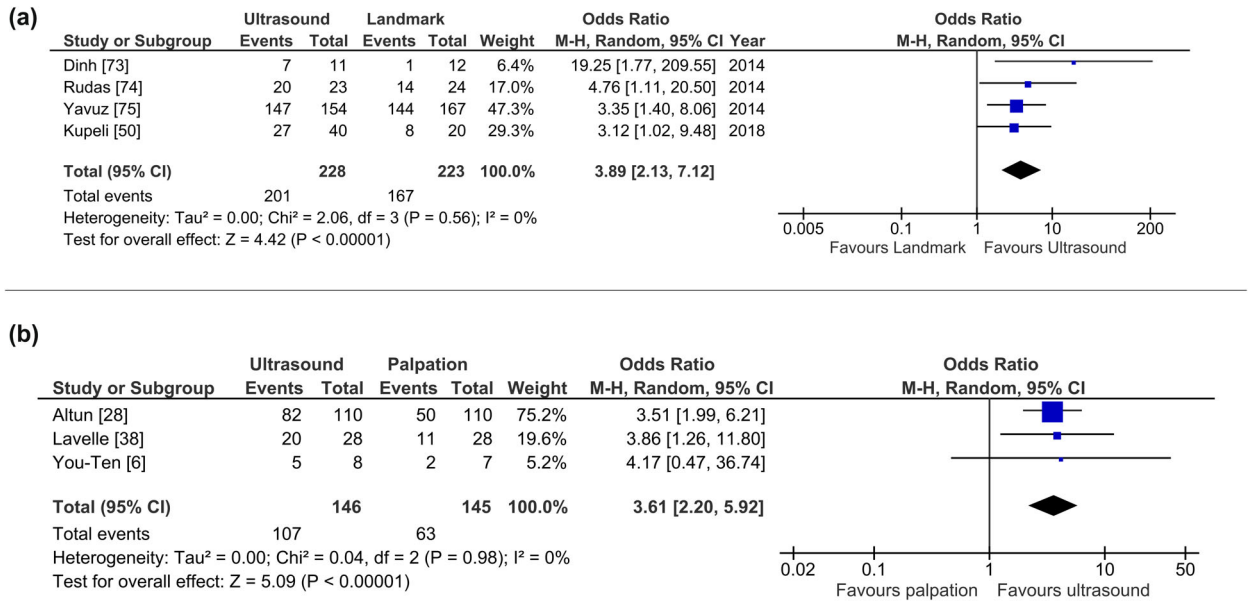
(a)
Ultrasound
Landmark
Odds Ratio
Odds Ratio
Study or Subgroup Events Total Events Total Weight M-H, Random, 95% CI Year
M-H, Random, 95% CI
Dinh [73] 7 11 1 12 6.4% 19.25 [1.77, 209.55] 2014
Rudas [74] 20 23 14 24 17.0% 4.76 [1.11, 20.50] 2014
Yavuz [75] 147 154 144 167 47.3% 3.35 [1.40, 8.06] 2014
Kupeli [50] 27 40 8 20 29.3% 3.12 [1.02, 9.48] 2018
Total (95% CI) 228 223 100.0% 3.89 [2.13, 7.12]
Total events 201 167
Heterogeneity: Tau² = 0.00; Chi² = 2.06, df = 3 (P = 0.56); I² = 0%
Test for overall effect: Z = 4.42 (P < 0.00001)
0.005 0.1 1 10 200
Favours Landmark Favours Ultrasound
(b)
Ultrasound
Palpation
Odds Ratio
Odds Ratio
Study or Subgroup Events Total Events Total Weight M-H, Random, 95% CI
M-H, Random, 95% CI
Altun [28] 82 110 50 110 75.2% 3.51 [1.99, 6.21]
Lavelle [38] 20 28 11 28 19.6% 3.86 [1.26, 11.80]
You-Ten [6] 5 8 2 7 5.2% 4.17 [0.47, 36.74]
Total (95% CI) 146 145 100.0% 3.61 [2.20, 5.92]
Total events 107 63
Heterogeneity: Tau² = 0.00; Chi² = 0.04, df = 2 (P = 0.98); I² = 0%
Test for overall effect: Z = 5.09 (P < 0.00001)
0.02 0.1 1 10 50
Favours palpation Favours ultrasound

Figure 2 Pooled data for cricothyrotomy and tracheostomy. (a) First pass success in percutaneous tracheostomy and (b) accuracy in identification of cricothyroid membrane.

information Figure S15). The certainty of evidence was judged to be high (online Supporting Information Table S3).

Surgical airways

Identification of cricothyroid membrane

Based on data from three studies [6, 28, 38], POCUS was associated with higher odds (OR 3.61 (95%CI 2.20–5.92)) of accurate identification of the cricothyroid membrane when compared with palpation (Table 2, Figure 2b). The certainty of evidence was judged to be moderate-high (online Supporting Information Table S4). We found no evidence of an effect of POCUS on cricothyroid membrane visualisation time when compared with palpation (mean difference -7.8 s (95% -26.56-11.6)) [28, 38, 71, 72].

Percutaneous tracheostomy

Four studies were analysed for their use of POCUS for percutaneous tracheostomy [50, 73–75]. Point of care ultrasound was associated with higher odds of first-pass success rates during percutaneous tracheostomy when compared with landmark techniques (OR 3.89 (95%CI 1.87–6.51)) (Table 2, Figure 2a). The certainty of evidence was judged to be low-moderate (online Supporting Information Table S4).

Sensitivity analysis revealed no statistically significant differences in results for facemask ventilation, laryngoscopy, tracheal intubation, tracheostomy and cricothyrotomy (online Supporting Information Table S5).

Discussion

We investigated the diagnostic accuracy and predictive ability of discrete POCUS parameters for difficult facemask ventilation, laryngoscopy, tracheal intubation and surgical airways. We identified several supra- and infra-hyoid parameters that, when combined with a focused history and clinical examination, have the potential to improve our predictive ability to diagnose and manage difficult airways.

For difficult facemask ventilation, tongue thickness and distance between lingual arteries appear to be the most promising parameters with reasonable sensitivity and specificity. For difficult laryngoscopy, distance from skin to vocal cords showed the highest sensitivity and specificity for predicting a difficult airway. In a hypothetical cohort of 1000 patients with an estimated prevalence of difficult laryngoscopy of 5% (50 true cases), this parameter would correctly identify 42 (84%) patients with difficult laryngoscopy (true positive) with eight cases missed (false negative). Among the 950 patients without difficult laryngoscopy, it would correctly predict 773 (81%) patients as not having the condition (true negative), with 117 incorrectly identified as having it (false positives). By comparison, the modified Mallampati test, with a sensitivity of 0.91 (95%CI 0.91–0.91) and specificity of 0.35 (95%CI 0.34–0.36) [1], would identify 46 true positives and only 332 true negatives in the same cohort. Thyromental distance, with a sensitivity of 0.48 (95%CI 0.43–0.53) and specificity of 0.79 (95%CI 0.78–0.80) [2], identifies 24 true positives and

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Table 3 Abbreviated Indication, Acquisition of image, Image interpretation and Medical decision making (I-AIM) table.

Location	I – Indication	A – Acquisition of image	I – Image interpretation	M – Medical decision making
Suprahyoid	Distance from skin to epiglottis	Position a linear transverse probe at the level of the mentum with the indicator directed towards the patient's right side. Slide the probe caudally, passing the oral structures and the hyoid bone, until the epiglottis is identified.	Utilise the `face sign´ to identify the epiglottis, which represents the `mouth´ in this sign. It appears as a hypoechoic curvilinear structure.	Measure the distance from the skin to the epiglottis. Cut-off for laryngoscopy is 2.70 cm and 2.37 cm for tracheal intubation.
Infrahyoid	Distance from skin to hyoid bone	Place a transverse linear probe at the mentum with the indicator to the patient's right. Slide caudally until the hyperechoic hyoid bone is visualised.	The hyoid bone appears as an inverted U-shaped hyperechoic line. Measure the distance from the skin to the hyoid bone.	Measure the skin-to-hyoid distance. Assess for difficult airway based on this value and proceed accordingly.
Infrahyoid	Distance from skin to vocal cords	Place a high-frequency linear probe transversely with the indicator to the patient's right. Identify the thyroid and cricoid cartilages, then slide caudally from the thyroid to visualise the vocal cords.	In the transverse view, vocal cords appear hypoechoic and are flanked by hyperechoic thyroid cartilage.	Measure skin-to-vocal cord distance. A value ≥ 5.98 cm suggests a difficult airway.
Infrahyoid	Cricothyrotomy for elective/ emergency airway access	Perform a transverse scan by sliding from the thyroid cartilage to the cricoid cartilage and then back to the cricothyroid membrane (TACA technique). Conduct a mid-sagittal scan over the thyroid and cricoid cartilages, identifying the hyperechoic cricothyroid membrane in between.	Find the level, mid-point and size of the cricothyroid membrane.	Cricothyroid membrane. Membrane localisation is valuable pre-operatively and in emergencies. Mark difficult airway findings on a scale and use them as reference. This aids in airway blocks and midline identification.
Infrahyoid	Tracheostomy	Slide the transverse probe caudally to visualise the thyroid, cricoid, and tracheal cartilages. The first tracheal ring lies just below the cricoid. Use Doppler to identify nearby blood vessels.	The tracheal rings appear as a series of semi-circles. The thyroid cartilage appears as a hyperechoic structure. It has a characteristic V-shape or U-shape in a transverse view.	Identify midline of trachea, avoiding anatomical structures like blood vessels and thyroid isthmus.

751 true negatives. The distance from skin to epiglottis is the parameter investigated most commonly for difficult laryngoscopy [9, 10]. Multiple studies have validated its utility and our pooled AUROC of 0.82 supports this finding. In contrast, tongue volume was the least predictive index, which is consistent with literature showing oral structure metrics having low diagnostic value [76].

For tracheal intubation, the skin to epiglottis distance, skin to hyoid-bone distance and the hyomental distance ratio 1 showed higher sensitivity and specificity than the thyromental distance and greater specificity than the modified Mallampati test. Notably, the skin to epiglottis and skin to hyoid bone distances had AUROC values > 0.80. Additionally, the double tract sign, a POCUS method for confirming tracheal tube placement and identifying inadvertent oesophageal intubation, has been highlighted as an alternative method to confirm tracheal intubation when capnography and auscultation are unreliable or unavailable [77, 78].

Our findings continue to support the clinical utility of POCUS in enhancing pre-procedural planning and patient safety during surgical airway management. By facilitating accurate identification of the cricothyroid membrane, ultrasound may lower the risk of complications in challenging cases (e.g. patients with obesity, distorted neck anatomy, coagulopathy). In percutaneous tracheostomy,

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use of short- or long-axis POCUS views serves different functions. Short-axis views identify anatomical structures, with a higher first pass success rate, while the long-axis view provides better views to trace the needle path [49].

Taken together, our data support the clinical potential of POCUS in upper airway management. The abbreviated I-AIM approach [79] is outlined in Table 3 and describes how to measure these POCUS parameters and their clinical implications. The full table can be found in the online Supporting Information Table S6.

Our study has strengths. This is the most comprehensive systematic review to date, encompassing a total of 10,580 patients across 60 studies. Where possible, we have reported pooled estimates to provide clinicians actionable insight into the utility of POCUS as a tool for difficult airway prediction. Study limitations include high heterogeneity of pooled data for laryngoscopy and tracheal intubation, and poor reporting of relevant comorbidities such as obstructive sleep apnoea. Furthermore, inter-rater reliability was reported poorly across the included studies; this may impact the acceptability and generalisability for broader use in clinical practice.

Our findings have implications for practice and future research. Practice implications include training and governance, as operator skill variability may impact accuracy. Structured training enhances the ability of clinicians to identify key landmarks, such as the cricothyroid membrane [8]. Workshops and certification from airway societies such as the Difficult Airway Society, American Society of Anesthesiologists and the Society of Sleep Medicine and Anaesthesia support skill development [80–82]. Regular updates and refresher workshops are essential to mitigate skill decay and promote novel applications [80, 83]. Institutional guidelines can further standardise the use of POCUS in airway management. Future research should prospectively evaluate the predictive accuracy of a combination of POCUS and clinical parameters in difficult airway management across many centres. Furthermore, the impact of POCUS in other clinically important settings, such as obstetrics and bariatric surgery, should be investigated due to the current paucity of data.

In summary, our study supports the potential for the incorporation of POCUS as part of the standard of care in airway assessment and management.

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Supporting Information

Additional supporting information may be found online via the journal website.

Plain Language Summary.
Figure S1. Risk of bias in included studies.
Figure S2. Publication bias in laryngoscopy studies.
Figure S3. Publication bias in tracheal intubation studies.
Figure S4. Publication bias in surgical airway studies.
Figure S5. Pooled diagnostic data for distance from skin to vocal cords in laryngoscopy.
Figure S6. Pooled diagnostic data for distance from skin to epiglottis in laryngoscopy.
Figure S7. Forest plots for laryngoscopy.
Figure S8. Pooled diagnostic data for distance from skin to hyoid bone in laryngoscopy.
Figure S9. Pooled diagnostic data for tongue volume in laryngoscopy.
Figure S10. Forest plots for tracheal intubation.
Figures S11–S15. Pooled diagnostic data for: Pre-E/E-VC; distance from skin to epiglottis; distance from skin to hyoid-bone; ratio between the hyomental distance in extended position to that in neutral position; and distance from skin to vocal cords, parameters in tracheal intubation.
Table S1. Study characteristics.
Table S2. Study values and key outcomes.
Table S3. GRADE tables for clinical data.
Table S4. GRADE table for management questions.
Table S5. Sensitivity analysis.
Table S6. Full I-AIM table.

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